

LESSONS FROM A CHILLED WATER STORAGE COOLING SYSTEM AT FORT JACKSON, SC

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ABSTRACT

A 8,517 m³ (2.25 million gal) chilled water storage cooling system has been in operation at Fort Jackson, SC since commissioning of the system in May 1996. The construction of the system was funded by the Energy Conservation Improvement Program (ECIP) and the system was designed and built by the Corps of Engineers Savannah District Office (CESAS). Technical information on the design and construction of the system was reported at an earlier Meeting at St. Louis in 1995. During the first year of operation in 1996, the system shifted more than 3 MW of electrical demand from on-peak to off-peak period. The electrical cost savings for Fort Jackson has amounted to about \$430K during the first year of operation. This paper reviews lessons learned from the project, including the performance from the first year of operation.

INTRODUCTION

Fort Jackson, SC has 0.97 million m² (10.4 million sq ft) of building space, provides housing and offices for 13,000 soldiers, 11,000 family members, and 3,500 civilian employees. A 8,517 m³ (2.25 million gal) capacity Chilled Water Storage (CWS) cooling system was installed on the Central Energy Plant (CEP) #2 at Fort Jackson. The CEP #2 meets more than half of the cooling requirements of Fort Jackson. The CWS cooling system was built by the Savannah District, U.S. Army Corps of Engineers (CESAS), in cooperation with the Directorate of Public Works (DPW), Fort Jackson, and the U.S. Army Construction Engineering Research Laboratories (USACERL). The total construction cost (\$1.9

million) was funded by ECIP. The local electrical utility, the South Carolina Electric and Gas Co. (SCE&G), provided a one-time incentive award of \$0.75 million. The system was commissioned in May 1996 by engineers from DPW, CESAS, and USACERL. During the commissioning, the system demonstrated a load shifting capability of 3.3 MW from on-peak to off-peak periods. At the current SCE&G electric rate schedule, the system is expected to save over \$430K/year in electric utility cost, for a system payback of less than 3 years.

The design and construction of the system was described in an earlier paper by CESAS reported at the 1996 E&M Conference [1]. Table 1 summarizes the salient characteristics of the CWS cooling system.

TABLE 1

CHILLED WATER STORAGE TANK SPECIFICATIONS

Cooling capacity	59,069 KwH (16,800 ton-hours)
Size	8,517 m ³ (2.25 million gal)
Mean diameter	29.9 m (98 ft)
Water level height	12.4 m (40 ft 7 in.)
H/D ratio	0.41
Plan area	700.8 m ² (7,543 sq ft)
Vertical core wall thickness	Tapers from 0.18 m (7-1/4 in.) at bottom to 0.089 m (3-1/2 in.) at top including 0.025 m (1-in.) cover over steel shell diaphragm
Vertical wall material	Prestressed composite wall (steel shell/shotcrete) with 0.127 m (5 in.) thick rigid Styrofoam insulation glued to concrete tank and finished "vee" rib outer sheeting; brick outer shell for bottom 2.34 m (7 ft, -8 in.)
Dome shell	0.067 m (3-in.) thick concrete with expanded polystyrene insulation
Floor	0.127 m (5 in.) concrete with painted outer surface

SYSTEM COMMISSIONING

BACKGROUND

As discussed in the earlier paper [1], the project has been divided in two phases. During the Phase I, the tank and the quadruple octagonal diffuser system inside the tank were

constructed in 1995. During the Phase II, modification of piping in the CEP #2 and connection to the tank were completed in early 1996. In March 1996, while preparing the tank for commissioning, a major breakage of upper diffuser assembly of the internal diffuser system was noticed. The tank was drained, the cause of failure was investigated, and the upper diffuser assembly was repaired for a successful system commissioning on 20 May 1996.

BREAKAGE AND REPAIR OF UPPER DIFFUSER ASSEMBLY

Note that the upper distribution diffuser system (Figure 1) is hanging from the ceiling with 0.0095 m (3/8-in.), stainless steel, threaded rods fixed to the dome roof. Figures 2 and 3, respectively, show the plan of the tank and the details of the diffuser system. About 26 breakage points in the upper diffuser system, including diffuser and riser (feeder line to diffuser), were noticed. The potential causes of failure and repairs made are:

- Buoyancy on the diffuser due to air pockets: At the initial tank filling with water, the tank was not connected to CEP #2. Water was introduced through the opening at the ceiling. The two 0.61 m (24-in.) main transfer lines (to and from the tank, shown in Figure 1) remained closed by isolation valves. Water was introduced into the diffuser assembly through the slots into the closed pipe space. The lower diffuser assembly is anchored to the concrete floor with aluminum mounting pads between the diffuser and floor. The pad and anchor holds the lower diffuser assembly securely against any potential buoyancy forces. On the other hand, the upper diffuser is secured by the 0.0095 m (3/8-in) rods, which cannot provide resistance to compression induced by potential buoyancy due to air pockets inside the upper diffuser assembly. The solution was to install a bypass line across the two 0.61m (24-in.) main transfer lines. A short 0.28 m (11-in.) pipe, with a shut-off valve in the middle, was installed between the two main transfer lines just outside the tank. When filling the tank, the bypass line will equalize the rising water level between the inside and outside of the diffuser system, thereby eliminating any potential buoyancy effects.
- Valve actuating speed: Line-sized butterfly control valves are installed at the outlet of recovery turbines in CEP #2. These valves open so quickly that it could induce water hammer effects along the line, including at the diffusers inside the tank. The solution was to slow down the valve opening and closing speed to 60 seconds for a full opening or closing of the valves.

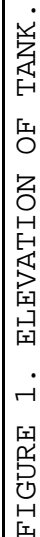


FIGURE 1. ELEVATION OF TANK.

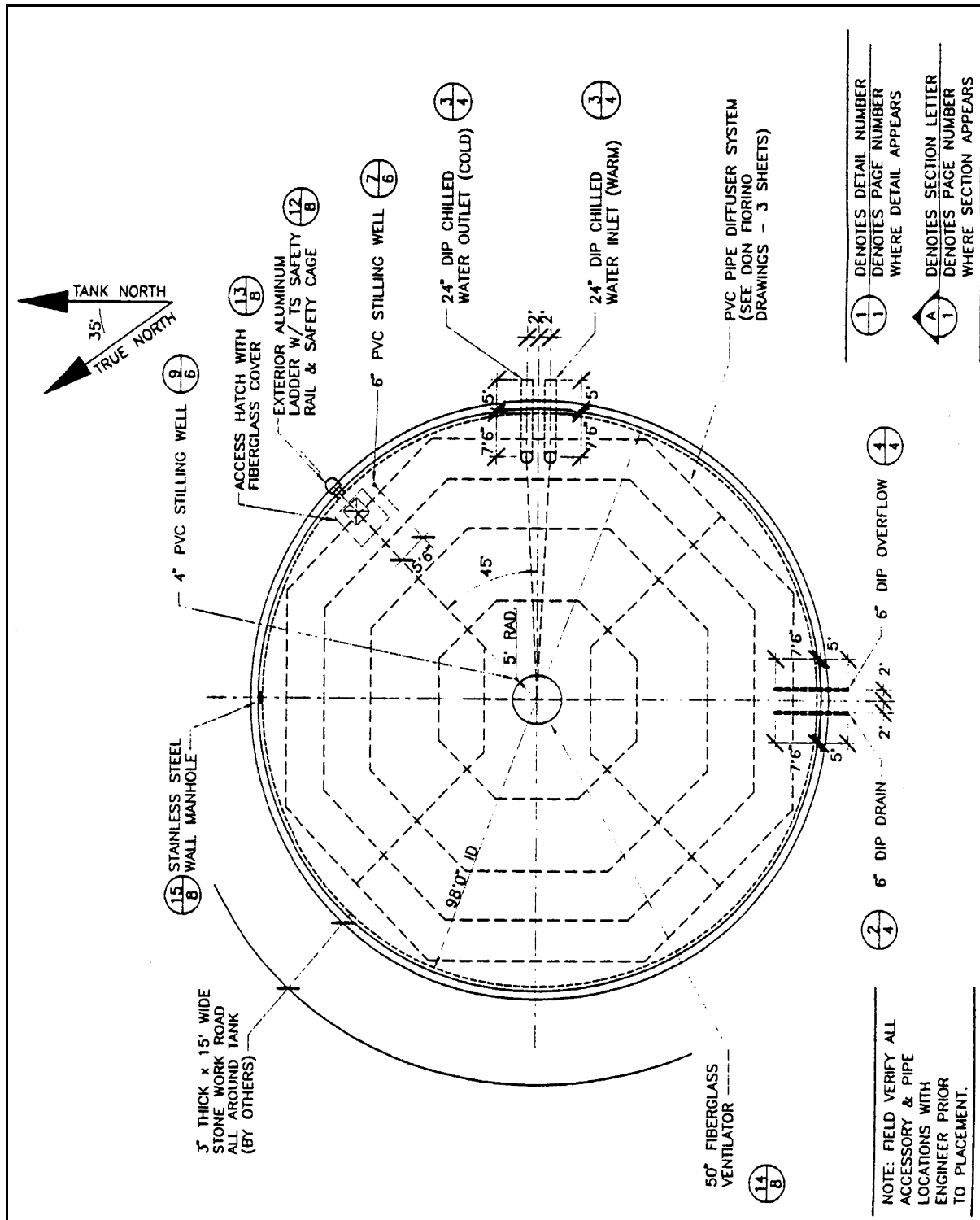


FIGURE 2. TANK PLAN.

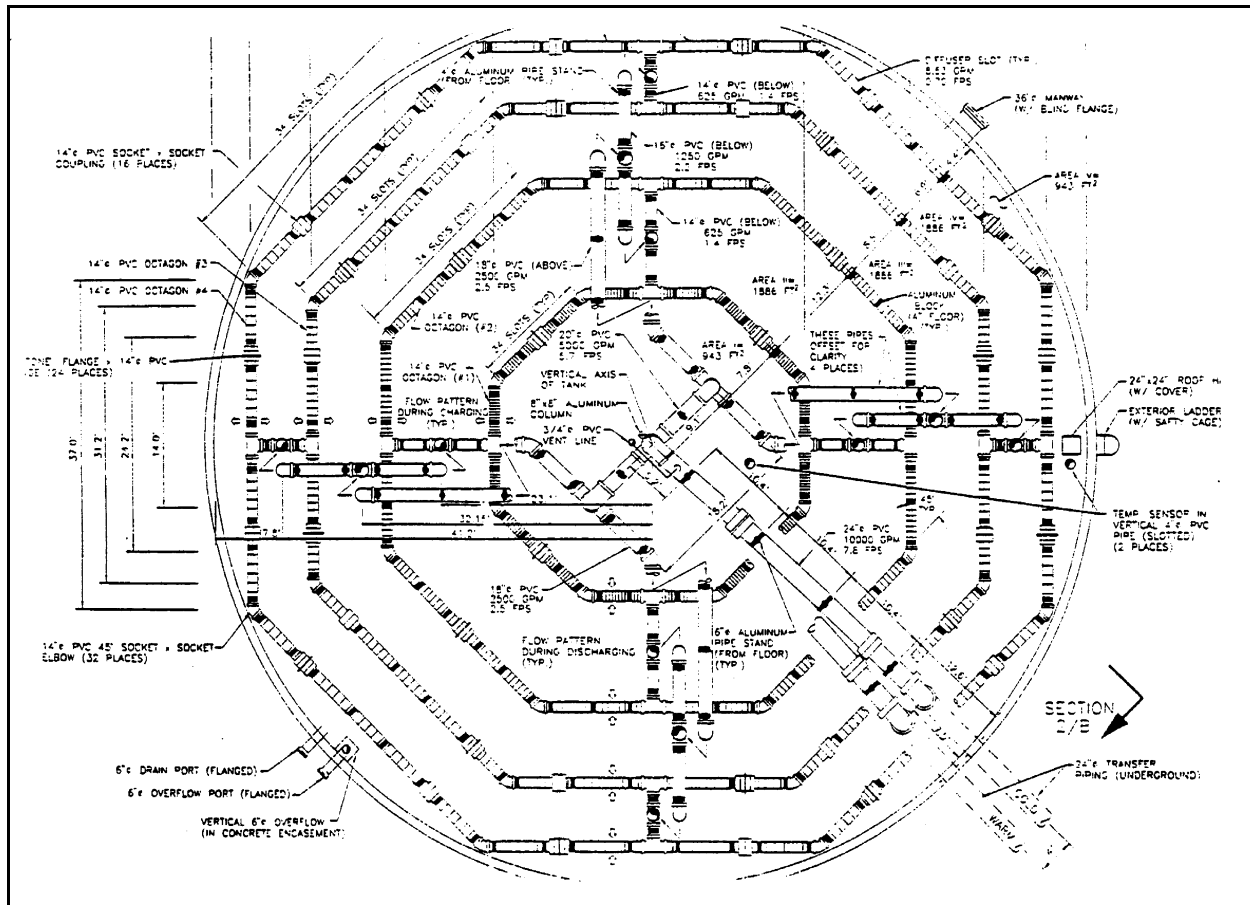


FIGURE 3. DETAILS OF DIFFUSER SYSTEM.

- Loose connection of main transfer line to upper diffuser: The flange bolts connecting the 0.61 m (24-in) steel main transfer line from CEP #2 to the 0.61 m (24-in) PVC line to the upper diffuser assembly (marked * in Figure 1) within the tank were missing nuts underneath the flange. The loose connection would have generated a significant flow-induced vibration of the upper diffuser structure when a full charge flow rate was introduced to the tank. The flange nuts were installed and tightened for a secure connection of the 0.61 m (24-in) main transfer line for the upper diffuser.
- Leveling of Upper Diffuser: The broken parts of the upper diffuser were fixed and the tank was fully charged with city water. One major concern was with leveling the upper diffuser segments. A DPW engineer entered the tank and measured the elevation of high spots along the diffuser segments. The maximum elevation differential at the highest spot was measured to be 0.127 m (5 in). The original design

water depth between the top surface of water and the highest point in the diffuser was 0.203 m (8 in). With the unevenness of up to 0.127 m (5 in), the operating water depth would be reduced down to 0.076 m (3 in) at the highest spot. In case of potential rapid loss of water in the system, e.g., a rupture in the distribution line, the 0.076 m (3-in) margin was deemed too shallow to prevent potential exposure of diffuser slots to the atmosphere. Exposure of slots to open air will introduce air into the circulation system. The solution was to raise the operating tank water level by 0.178 m (7 in) by extending the overflow level from 12.19 m (40 ft) to 12.37 m (40 ft 7 in). The tank builder was consulted for the safety of the raised level of water.

COMMISSIONING OF SYSTEM

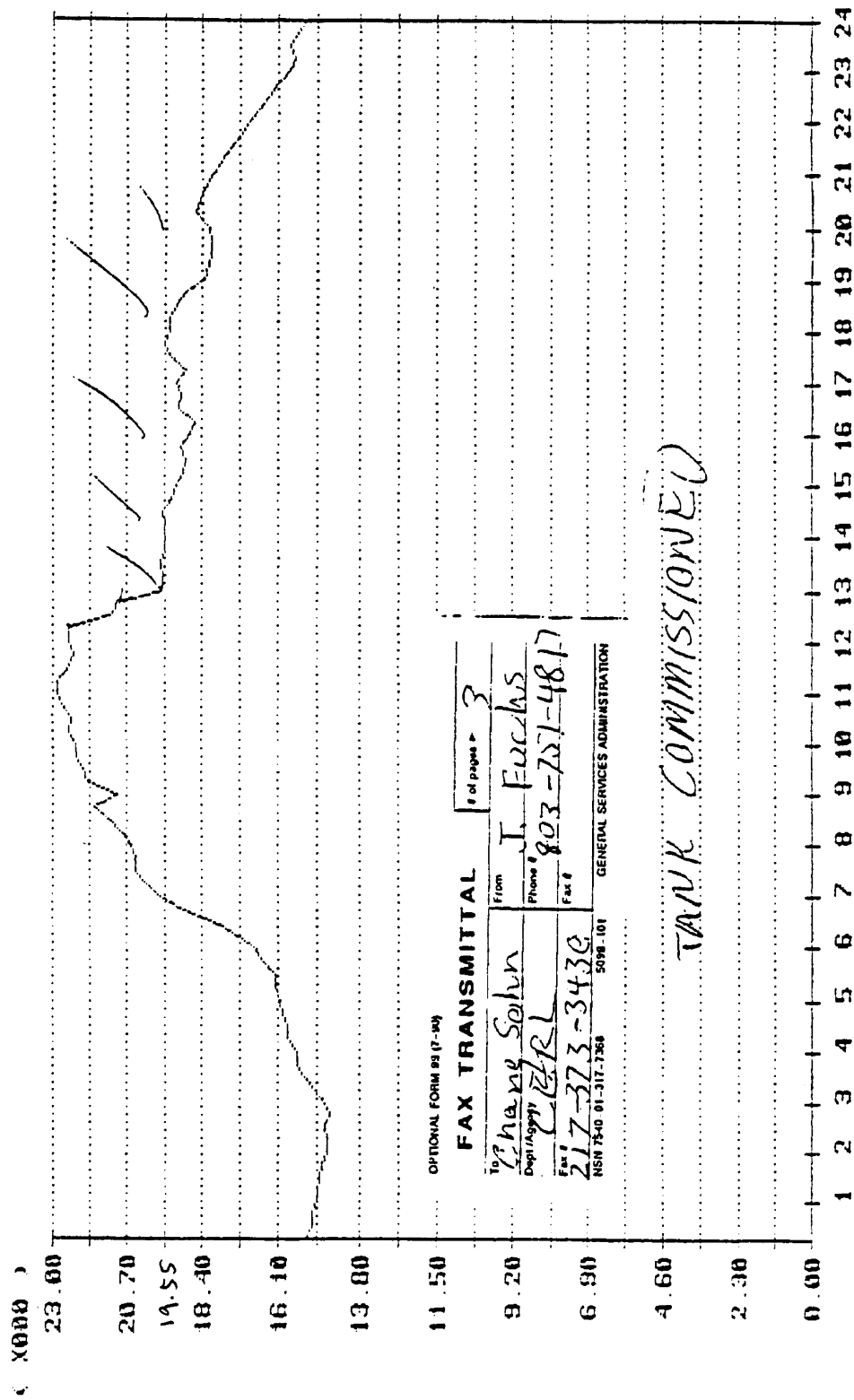
The tank was filled with city water, and chillers in CEP #2 completed charging the tank with chilled water during the weekend of 18 May 1996. The tank was fully charged by the early morning of 20 May 1996 (Monday). The temperature profile inside the tank ranged from 4.4 °C (40 °F) at the bottom to 6.1 ° (43 °F) at the top of the tank.

The ambient temperature in Columbia, SC on 20 May was up to 37.2 °C (99 °F). By noon, all four chillers (1200 ton each) in the Energy Plant #2 were running to provide cooling for Fort Jackson. Starting from 1222 (20 May 1996), all the four chillers were shut down: #1 chiller at 1222, #2 at 1252, #3 at 1307, and #4 at 1320. Note that the utility on-peak hours for Fort Jackson are between 1300 and 2100. The chilled water in the tank was meeting the entire cooling load during the peak hours. The chillers were brought back to on-line starting at 1622 for #1, #2 at 1007, #3 at 1722, and #4 at 1807. This operation helped Fort Jackson keep its on-peak billing demand under 19,550 kW (Figure 4, Hourly Load Profile of Fort Jackson, 20 May 1996). On 20 May 1996, the electrical demand was peaking around 1100 at 23,000 kW. Without the shutdown of the four chillers, the demand should have increased to over 23,000 kW in the early afternoon hours. Therefore, the minimum amount of peak shaving by the storage tank is 3450 kW (the difference between 23000 kW and 19550 kW). Table 2 shows the thermal performance of the tank for the first complete cycle of charging and discharging; Table 2 lists the temperature distribution inside the tank at a number of benchmark hours. Note that, for the first day of operation (20 May 1996), the tank was not discharged fully. Table 2 confirms the regenerating capability of the tank thru the night of 20 May. By the morning of 21 May 1996, the tank was fully recharged and ready to repeat the cooling cycle.

Id 1100011 DAILY LOAD PLOT Chan: 1 05/21/96

Name: FORT JACKSON Start: 05/20/96 00:01 Max: 22886.4 KII

15 Min Clock Intervals Stop: 05/20/96 24:00 Min: 14643.2 KII



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FAX TRANSMITTAL

3 of pages

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NSN 7540-01-317-1268 5096-101 GENERAL SERVICES ADMINISTRATION	

TANK COMMISSIONED

Hour's

FIGURE 4. HOURLY LOAD PROFILE OF FORT JACKSON, 20 MAY 1996.

TABLE 2

TEMPERATURE DISTRIBUTIONS INSIDE THE TANK

Sensor #	Date/Time 20 May 1996 (1710 EDT) °C/°F	Date/Time 21 May 1996 (0830 EDT) °C/ °F	Date/Time 22 May 1996 (0830 EDT) °C/ °F
20 (top)	13.8/56.9	6.7/44.0	7.3/45.2
19	13.5/56.3	6.7/44.0	7.2/44.9
18	13.2/55.8	6.6/43.8	7.0/44.6
17	12.8/55.0	6.5/43.7	7.0/44.6
16	11.8/53.3	5.9/42.7	6.4/43.6
15	11.1/51.9	5.9/42.6	6.1/42.9
14	10.6/51.1	5.4/41.7	5.8/42.5
13	10.2/50.4	5.3/41.5	5.8/42.4
12	9.9/49.9	5.3/41.5	5.7/42.3
11	5.5/41.9	4.9/40.9	5.4/41.7
10	4.8/40.7	5.3/41.5	5.7/42.3
9	4.3/39.8	4.8/40.6	5.2/41.3
8	4.2/39.6	4.7/40.4	4.9/40.9
7	data missing		
6	data missing		
5	data missing		
4	4.8/40.7	4.8/40.6	5.5/41.9
3	4.9/40.9	4.8/40.7	5.7/42.2
2	4.9/40.9	4.7/40.4	5.5/41.9
1 (bottom)	data missing		

SYSTEM OPERATION

Since 20 May 1996, the tank operated as a part of the CEP #2 cooling system through the end of 1996 cooling season. During early May 1996, while repairing the diffuser, corrosion of

aluminum parts installed inside the tank (i.e., support structure and pads for the lower diffuser segments) was observed. By late May 1996, the cooling load of Fort Jackson became significant contribution to the peak electrical demand. Due to lack of time, it was decided to bring the tank on line and serve out the 1996 cooling season, then the aluminum parts would be checked again for determination of further actions at the end of the 1996 cooling season. Note that the corrosion of support members is not related to the thermal performance of the chilled water storage systems.

At the end of the 1996 cooling season, the tank was drained to inspect the integrity of the components inside the tank. On 23 January 1997, the progress of corrosion on the support structure due to dissimilar metal contact inside the tank was examined by the USACERL and DPW engineers. The rate of progress was determined to be slow enough not to warrant immediate replacement of the supporting parts. A decision was made at the field inspection that the system would be operated without any replacement of components for the next 5 years. It was recommended that the tank be drained at the end of the 2001 cooling season and inspected for any remedial actions needed. To prevent further corrosion damage, the tank water was treated for corrosion inhibition at the beginning of 1997 cooling season. The treatment formula, recommended by USACERL and the U.S. Army Center for Public Works, Alexandria, VA (USACPW), were:

- The treatment for aluminum, stainless steel and steel components is: Poly Silicate with SiO_2 to NaO_2 ratio equal to 3.22. The dosage is 200 ppm as SiO_2 (Liquid)
- The treatment for copper is: Toly Triazole (TT) 50% sodium tolytriazole. The dosage is 50-100 ppm.

SYSTEM PERFORMANCE

ELECTRICAL COST SAVINGS IN 1996-97

The electrical cost savings by the operation of the CWS cooling system for a year (June 1996-May 1997) was estimated based on the monthly electrical utility bills for Fort Jackson. Table 3 shows the monthly billing demands for Fort Jackson during the past 4 years. Note that the annual peak demand for Fort Jackson has been reduced from 25,358 kW in 1995 to 23,424 kW in 1996 with operation of the CWS cooling system.

TABLE 3

MONTHLY BILLING DEMAND IN KW FOR THE PAST 4 YEARS

month	1	2	3	4	5	6	7	8	9	10	11	12
1994	17485	17485	17485	17485	19008	23155	22896	22810	22810	17485	18524	18524
1995	18524	18524	18524	18524	20822	22896	24408	25358	22896	21470	20286	20286
1996	20286	20286	20286	20286	21456	23136	23424	22752	21840	19872	17856	17856
1997	17856	17856	17856	17856	19584	23328	24768	24432	22560	19920	18662	

Table 4 shows the monthly electrical energy consumption for Fort Jackson during the last 4 years. For each of the 12-month period (June through May), the annual total energy consumption is 114.84 GwH in 1994-5, 122.69 GwH in 1995-6, and 120.2 GwH in 1996-97. Note that the total energy consumption depends on the level of installation activities as well as fluctuating annual climate conditions. Quantitative determination of energy savings cannot be made from the monthly billing information.

TABLE 4

MONTHLY ENERGY CONSUMPTION IN GWH FOR THE PAST 4 YEARS

month:	1	2	3	4	5	6	7	8	9	10	11	12
1994	6.97	8.15	7.38	8.04	9.84	11.85	12.96	13.16	11.01	7.57	8.28	7.38
1995	7.94	7.78	7.6	8.79	10.52	11.65	14.93	13.63	12.15	10.09	8.26	8.5
1996	7.75	8.29	8.1	8.67	10.67	11.79	14.1	12.8	9.43	12.23	8.39	9.11
1997	8.17	8.61	8.55	8.01	9.01	12.19	14.22	13.21	13.08	10.7	8.52	

Table 5 summarizes the monthly electrical bills for the past 4 years. A monthly bill has two components: one is for the demand charge based on the billing demand (in kW) each month Table 3, and the other for the energy charge based on the monthly energy consumption (in kWh) shown in Table 4. A sum of the demand charge and the energy charge is the monthly electrical charge for Fort Jackson.

Table 6 summarizes impact of the CWS cooling system on the annual electrical utility cost for Fort Jackson. It shows changes in the electrical cost for each of 12-month (June-May) period during the past 4 years. For the first 12-month operation of the CWS cooling system, the system reduced the electrical cost for Fort Jackson from \$5.46M in 1995-96 to \$5.16M in 1996-97. During the 1996-97 period, a number of large buildings were added to Fort Jackson. Even with the increased electrical energy demand and consumption by these new buildings, the total electrical bill was reduced by \$0.3M during the first 12-month operation of the CWS cooling system. Note that the annual electrical utility cost for Fort Jackson has been increasing during the past years, i.e.,

\$5.02M in 1994-95 and \$5.46M in 1995-96. Without the CWS cooling system, the trend will continue and the cost during 1996-97 would have been significantly higher than the cost during 1995-96.

TABLE 5
MONTHLY ELECTRICAL COST (\$) FOR THE PAST 4 YEARS

Month	1	2	3	4	5	6	7	8	9	10	11	12
1994-KW	116,015	115,805	116,015	121,097	143,260	324,638	321,015	319,811	319,811	128,919	145,558	145,558
1994-	136,472	158,824	144,501	157,874	188,738	291,494	315,226	320,185	268,695	156,891	174,155	156,697
1994	252,487	274,629	260,596	278,971	331,998	616,132	636,241	639,997	588,507	285,810	319,713	302,255
1995-KW	145,558	145,558	145,558	145,558	163,528	321,015	342,168	355,458	321,015	167,698	159,337	159,337
1995-	167,357	165,185	161,245	185,516	211,028	277,848	348,405	324,302	289,389	201,679	169,486	172,565
1995	312,915	310,743	306,803	331,074	374,556	598,863	690,573	679,760	610,404	369,377	328,823	331,902
1996-KW	176,628	193,920	193,920	193,920	202,873	296,885	309,248	299,158	286,737	188,624	170,811	170,811
1996-	159,192	171,092	166,915	177,570	210,167	275,235	321,835	298,411	218,449	241,277	169,937	182,338
1996	335,820	365,012	360,835	371,490	413,040	572,120	631,083	597,569	505,186	429,901	340,748	353,149
1997-KW	172,953	172,953	172,953	172,953	189,107	312,323	327,022	320,113	303,166	190,721	163,378	
1997-	164,450	174,543	171,965	163,332	174,907	278,116	324,871	304,166	296,461	208,501	169,988	
1997	337,403	347,496	344,918	336,285	355,015	590,439	651,893	624,279	599,627	399,223	333,365	

TABLE 6

ANNUAL ELECTRICAL UTILITY COST FOR THE PAST 4 YEARS

12-month (Jun-May)	Demand cost (\$)	Energy cost (\$)	Total cost (\$)	Demand/Total
1994 - 1995	2,451,070	2,573,674	5,024,744	0.4878
1995 - 1996	2,787,289	2,668,610	5,455,899	0.5109
1996 - 1997	2,603,193	2,556,679	5,159,872	0.5045

Therefore, the actual impact of the CWS cooling system on the cost savings will be significantly more than \$0.3M. The actual saving is estimated to be close to \$0.43M based on the demand-shift capability of the system measured during the field test on 20 May 1996 (see "Economic Performance" below).

THERMAL PERFORMANCE OF THE SYSTEM

The thermal efficiency of the storage tank depends on the creation and maintenance of a sharp thermocline inside the tank during operation. A snapshot of the thermocline characteristic has been plotted with a three-channel temperature recorder (Figure 5). The three thermocouples were located vertically 15 ft apart each inside the tank. The thermocline took 6 hrs (from 2320, 23 September 1997 to 0520, 24 September 1997) to travel 9.14 m (30 ft) vertically between the bottom and top sensors. That corresponds to a charging flow rate of $0.296 \text{ m}^3/\text{s}$ (4688 gpm), which yields the charging inlet Reynolds Number of 760, based on the total diffuser length of 259.4 m (851 ft).

It is widely accepted that a charging Reynolds Number of less than 1000 establishes and maintains a good thermocline inside the tank [ASHRAE Cool Storage Design Guide, 1993]. Figure 5 shows movement of a sharp thermocline inside the tank during the charging process through the night of 23-24 September 1997. The calculated depth of the thermocline ranges from 0.305 m (1 ft) at the bottom level, and 0.457 m (1.5 ft) at the mid-level and 0.610 m (2 ft) at the top level in the tank. Based on the 2 ft thickness of thermocline, a theoretical charge efficiency of the tank is calculated to be 95% (38/40). A sharper thermocline is expected to yield a better storage efficiency. The measurements of thermocline movement inside the tank (Figure 5) demonstrate the diffuser system is working properly. It is believed that a large number of similar systems are operating with the thermocline thickness in the range of up to 1.524 m (5 ft). For the Fort Jackson system, creation and maintenance of thermocline with a thickness less than 0.610 m (2 ft) shows an excellent thermal performance of the system.

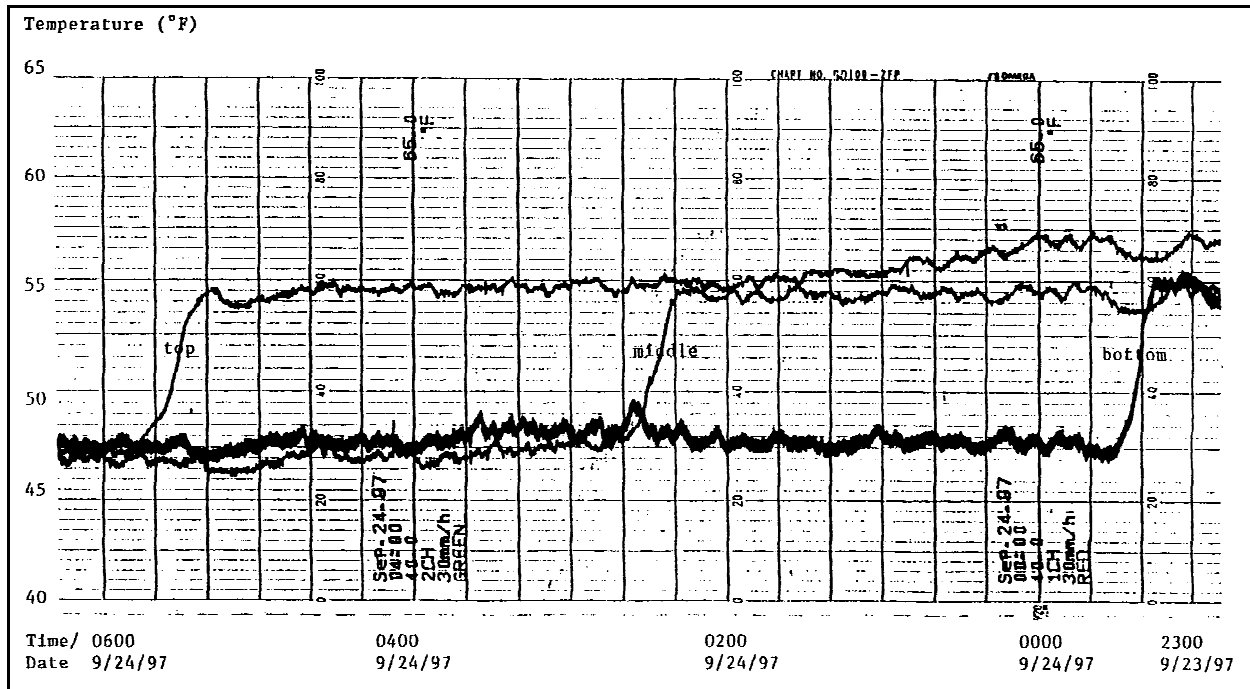


FIGURE 5. PROFILE OF THERMOCLINES WITHIN THE TANK.

ECONOMIC PERFORMANCE

The most significant benefit of the CWS cooling system is reduction in annual on-peak electrical demand of Fort Jackson. Due to the increasing level of activities at Fort Jackson, the annual peak demand has been growing 23,088kW in 1989 to 25,358kW in 1995. Commissioning of the system at the beginning of 1996 cooling season reduced the annual peak demand to 23,424 kW in 1996, thereby reducing the on-peak electrical demand by 1,934 kW compared to the year before. During the first 12-month (June 1996-May 1997) operation of the system, the annual electrical utility cost for Fort Jackson has been reduced from \$5.46M in 1995-6 to \$5.16M in 1996-7 period. Note that during the 1997-7 period, a number of large buildings were added to Fort Jackson inventory, which increased consumption of electricity. Therefore, actual savings during the first year of operation is a sum of \$0.3M (savings reflected in the monthly bills), the increased electrical utility costs incurred by the new buildings brought on-line during the 1996-7 period, and yearly inflation of electrical utility cost.

A more realistic cost saving can be estimated from the commissioning data (Figure 4). By the time all four chillers in the Plant #2 were unloaded at 1320, 20 May 1996, the electrical demand registered by the Fort Jackson master meter had dropped

from 23,000 kW at 1100 to 19,550 kW at 1320. This shows the system capability in demand reduction by 3450 kW. Each of the four chillers is rated at 4219.2 kW (1200 ton) capacity. For a total cooling tonnage of 16,876.8 kW (4800 ton), the electrical demand of 3450 kW yields the chiller kW/ton ratio of 0.72 kW/ton, which is quite reasonable for the centrifugal chillers. Based on the demand reduction of 3,450 kW and the prevailing electrical rate structure of the South Carolina Electric and Gas Company, the annual cost savings is estimated to be \$0.43M/yr.

LESSONS LEARNED

PROJECT EXECUTION

An implementation of chilled water storage (CWS) to a central energy plant (CEP) requires a careful project schedule. An immediate concern is that a CEP serves a large number of cooling customers. Therefore its operation cannot be disrupted, especially during the cooling season. For the Fort Jackson project, the connection of the tank to the CEP #2 in the late spring of 1995 was seriously considered as an option. There were three options: no cooling during the connecting piping work up to 1-1/2 week, a temporary cooling provision, or delay of the project until the end of the cooling season. The first option was unacceptable to Fort Jackson. A quote for the temporary cooling during the outage of CEP #2 was received at a cost of \$1.07M, based on a 6-week period, including set-up and tear-down. Due to high cost of the option, the project was delayed until the end of 1995 cooling season. By the time when the Phase II was completed in March 1996, the 1-year warrantee on the tank construction had expired. When the breakage of the upper diffuser assembly was found out in March 1996 (See Section 2.2), it was not clear when the failure had occurred: during the testing of the tank in early 1995, or during the commissioning test in March 1996. A completion of the project by a single source contractor would have avoided such confusion.

DESIGN AND CONSTRUCTION

The diffuser system inside the tank is the most critical element in successful performance of CWS cooling system. The octagonal diffuser system used in the Fort Jackson system (Figure 3) yielded excellent performance, as Figure 5 shows. It was designed following the recommended design criteria of inlet Reynolds number less than 850, as suggested in the current industry design guide by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) [2]. According to the ASHRAE guide, "For tall tanks, 40 ft (12 m) deep

or more, there is evidence that diffusers with inlet Reynolds number of 2,000 or more may provide acceptable stratification. For design purposes, a maximum of 2,000 for the Reynolds number should be used. In general, an upper limit of 850 is recommended, unless data are available for a specific tank to support proper stratification at higher Reynolds numbers."

The strict requirement in the inlet Reynolds number criteria (less than 850) resulted in a rather complicated diffuser system (quadruple octagonal diffuser, Figure 3) for the Fort Jackson system.

For future applications, a double octagonal diffuser is recommended for a cylindrical tank. The double octagonal configuration will reduce the total length of the diffuser by a factor of two, thereby raising the inlet Reynolds number of a quadruple octagonal configuration by the same amount. The Reynolds number criteria may be increased up to 2000 for future tanks of height at least 12.2 m (40 ft) tall. Careful attention should be given to the number and size of slots for each diffuser segment. For the Fort Jackson system, the total cross-sectional area of slot outlet was designed to be the same as that of the 0.610 m (24-in) main transfer pipe. Operators at Fort Jackson expressed concerns for increased pressure drop across the tank loop. For future design, the total cross-sectional area of slot outlet will be designed to be a minimum of 150% of the cross-sectional area of the main transfer line. The increased outlet area will reduce the pressure drop across the tank and will reduce the outlet jet speed to achieve a better thermal stratification. Study of an optimal design Reynolds number is ongoing. Preliminary results will be available to the design community in late 1998 [3].

The Fort Jackson system experienced significant corrosion of aluminum components inside the tank. Careful attention should be given to the specifications of material inside the tank to avoid potential corrosion. Generally speaking, aluminum and copper components are not recommended inside the tank. A bypass line between the two main transfer lines to the tank should be installed right before entrance to the tank. The segment should be equipped with a manual butterfly valve to isolate the two main transfer lines during normal operation. The valve will remain open only during the filling and draining of the tank to eliminate potential air pockets inside the diffuser system. The size of the bypass line could be half of the main transfer line, which showed itself to be working well for the Fort Jackson system. To avoid potential water hammer damage, all the valve actuators must be slow acting ones. Use of an adjustable speed drive for main circulation pumps is an good approach to avoid

fluid transient problems and to provide optimal control for cooling service. Close inspection of construction workmanship to match the design specifications is important for the success of a project. Particular attention should be given to the construction and installation of diffuser segments and leveled installation of upper diffuser assembly.

COMMISSIONING AND OPERATION

The commissioning process should begin with a final inspection of workmanship and acceptance testing of the system. The most critical phase is the initial filling of the tank with city water. An accurate reading of flowmeter in the main transfer line is a critical item to be verified. The contractor should have developed a detailed procedure for filling the tank to avoid damage to the structure inside the tank. Tank integrity should be tested with a fully charged tank. The operation of a level sensor should be checked when the tank water level reaches near the design height. A proper operation of the level sensor is critical to avoid potential exposure of upper diffuser slots to the atmosphere during an emergency loss of water from the system. Note that the tank is a part of the entire cooling loop, and any loss of water (at the building or along the distribution line) will result in a lowering of the tank level unless makeup water is supplied on time. A dial pressure gauge located at the bottom of tank is a useful guide to check the filling rate into the tank.

Water should be treated as local requirements specify. Note again that the water in the tank is circulating along the entire cooling loop including distribution systems and buildings. Treatment of water for required protection of coils and pipes should be equally applied to the water filled into the tank.

When the tank is completely filled with city water, the temperature sensors (installed at 2-ft interval from top to bottom) should provide uniform temperature distribution vertically. It is critical to verify accurate reading of temperature sensors and flow meters installed in the main transfer lines for acceptance testing and for future successful operation of tank. The flow rate inside the main transfer line and the differential temperature between the two main transfer lines determine the amount of cooling stored into the tank and cooling delivered by the tank. Once again, this emphasizes the importance of a flow meter in the main transfer line and temperature sensors across the two main transfer lines. A project implementation guide by ASHRAE [4] details further recommendations for acceptance and commissioning testing.

CONCLUDING REMARKS

Fort Jackson, USACE Savannah District and USACERL built a large capacity (8,517 m³, 2.25M gal) chilled water storage cooling system for the Central Plant #2 at Fort Jackson, which serves more than half of Fort Jackson's cooling load. The system completed a successful operation for 2 years, resulting in an annual electrical utility cost savings of \$0.43M for Fort Jackson. The system performed successfully, exceeding the original design goal of shifting 3200 kW of on-peak demand to off-peak periods. During the commissioning testing on 20 May 1996, the system reduced Fort Jackson's post-wide electrical demand by 3450 kW when the four chillers in CEP #2 were unloaded with cooling provided by the storage tank. A review of the monthly electrical utility bills showed a significant reduction of Fort Jackson's ever-growing annual electrical on-peak demand. Valuable lessons were learned during the system's design, construction, and operation. Two more chilled water storage cooling systems are currently under construction by the Savannah District: one for the CEP #1 at Fort Gordon, GA, and the other for CEP #1 at Fort Jackson, SC. Lessons from the Fort Jackson CEP #2 project will serve a useful guide for successful construction and operation of these systems.

REFERENCES

1. Stephen T. Burch, "Chilled Water Storage Tank Design Fort Jackson, SC," *Proc. 1995 USACE Electrical and Mechanical Engineering Training Conference*, pp. 252-258.
2. *Design Guide for Cool Thermal Storage* (ASHRAE, 1993).
3. "Parametric Dependence of the Performance of Stratification in Thermal Storage Tanks," ASHRAE Research Project 992-RP, project duration Apr 1997- Oct 1998.
4. *Guide to Successful Implementation of Cool Storage Projects*, Final Report, ASHRAE 850-RP, May 1996.

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